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PHOTOGEOLOGIC INTERPRETATION

USING PHOTOGRAMMETRIC DIP CALCULATIONS

By D. H. ELLIOTT

PHOTOGEOLOGIC INTERPRETATION USING PHOTOGRAMMETRIC DIP CALCULATIONS*

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OUTLINE OF REPORT

ILLUSTRATIONS

ABSTRACT

A method of calculating the angle of inclination of hill slopes and of strata on vertical aerial photographs, as developed in this paper, requires no instrument other than a pocket stereoscope. Besides the stereoscope, only a sheet of transparent acetate and a millimeter scale are needed. The calculations generally have an accuracy to within plus-or-minus 10 percent of the value observed in the field (except possibly for dips approaching horizontal or vertical) as demonstrated in a small number of field checks.

All calculations are based on the geometry of the camera lens and the photographic film. Consequently, in order to calculate the dip, it is not necessary to know the scale of the photograph, nor the height of the airplane above the ground, nor the absolute elevation of the top or bottom of the dip slope or bedding trace, nor the absolute elevation of any point on the ground. This is possible because photo distances are proportional to corresponding ground distances if both are related to a common datum.

A line of profile across the photographs can be drafted using a variation of the transparent overlay method.

Parts of the Nipomo and Lodoga quadrangles covered by aerial photographs have been interpreted both for

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** Photogeologist, Stanolind Oil and Gas Company, Casper, Wyoming.

geology and for dip calculations from the photographs, and these interpretations were checked in the field.

INTRODUCTION

Dip calculations may be made on vertical aerial photographs without the use of any instrument (except the pocket stereoscope) using methods developed in this paper. In addition to the pocket stereoscope, a sheet of transparent acetate and a millimeter scale are needed to make the photo measurements necessary to solve for the angle of dip. No calculations need be made to solve for the angle of dip if the nomogram (fig. 9) is utilized.

The methods presented here are especially useful for geological studies in measuring the inclination of strata for structural interpretation—either from bedding traces or dip slopes—and for soil erosion, forestry, engineering, and military studies in measuring the angle of hill slope. To simplify discussion, the term "dip slope" is used for a hill slope whether or not this slope is controlled by a bedding plane; the term "strike" is used for the direction of a horizontal line on this slope surface; and the term "dip" refers to the inclination in the direction of steepest slope.

All photogeologic interpretation involving dip calculations, lithology, or structure must be checked in the field. This is essential, for in many cases interpretation is based on topographic expression simulating normal lithology or structure, but which cannot be correctly interpreted from a study of the photographs alone.

Field geologists and other persons using vertical aerial photographs generally avoid photogrammetric dip calculations on them because of a distrust of the accuracy obtainable. It is true that a small amount of tilt may so affect the calculated dip as to give misleading results, but the tilt present in most vertical aerial photographs rarely exceeds 1 degree. Accordingly, dip calculations made by assuming the photographs to be truly vertical will not be seriously in error. New techniques in aerial photography are expected to eliminate any appreciable tilt (more than 1 degree), and precise dip calculations can then be made.

The simple procedures for dip calculations are described in sufficient detail so that any worker familiar with aerial photographs can calculate the angle of dips or slopes without having had prior photogrammetric experience.

The basic requirement for making dip calculations on vertical aerial photographs is the presence of a recognizable dip slope or a bedding trace on irregular topography. Points "u" (the upper point on a dip slope or bedding trace) and "*l*" (the lower point of a dip slope or bedding trace) are terms used throughout this paper. These two points do not have to be on the line of dip from each other for dip calculations.

A source of error inherent in measuring the angle of dip slopes is the assumption made by the geologist that the hill slope and bedding plane are coincident. Actually the lower part of the slope may be covered with talus, causing the slope to have a smaller dip than the underlying strata. Although this error cannot be adjusted photogrammetrically, it is generally small if the geologist is discriminating.

Dip calculations presented here are based on the geometry of the camera lens and the photographic film, and not on the geometry of the airplane and the ground (fig. 1). Consequently, it is not necessary to know the sca of the photograph, nor the height of the airplane abo the ground, nor the absolute elevation of the top or botto of the dip slope, nor the absolute elevation of any poi on the ground. Moreover, this information generally not available. Instead, photo measurements of horizont distances which have been corrected for displacemen together with the focal length (f) of the camera ler and a measurement of the difference in parallax (dp (sec. IIF) are used.

In this paper, upper case letters in equations refer t points on the ground; lower case letters refer to co responding points on the photograph. All measurement should be made in the same units, and are specified i millimeters for photo points and in feet for ground points

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II. BASIC PHOTOGRAMMETRIC THEORY AND CONSIDERATIONS

A. Preliminary Considerations

In all calculations, photogrammetric definitions, and geometrical relationships in this paper, an absence of tilt is assumed as is the constant altitude of the airplane. Vertical aerial photographs flown by present-day standards are taken from nearly the same altitudes, and generally with but a small tilt. If precise photogrammetric dip calculations are required, the photograph may be rectified for tilt. With only three horizontal and vertical control points optimumly located on a stereo pair, tilt and the difference in altitude (which is directly related to scale) can be corrected by the procedures of Anderson.[1] However, to make approximately correct dip calculations, aerial photographs are considered truly vertical and taken from the same altitude.

B. General

A vertical aerial photograph represents a perspective view taken from a single camera station. The **center point** (photo center or principal point) of the photograph represents the point on the ground directly beneath the camera or air station at the moment of exposure of the photographic film. The **transferred center** is the point on one photograph representing the center point of the adjacent photograph.

The **scale** of a vertical aerial photograph has the following relationship:

$$\text{scale} = \frac{\text{focal length of camera lens}}{\text{height of airplane above the ground}}$$

Therefore, the scale varies from place to place on the photograph depending upon the elevation of the differ-

[1] Anderson, R. O., Applied photogrammetry, 4th ed., Ann Arbor, Edwards Brothers, 1946.

nt ground points. Because the exact height of the air-lane above any specific ground point is seldom known, ie exact scale for that point on the photograph is seldom btainable. To avoid the problem of varying scale, the alculations of this paper do not directly use the photo cale. Consequently, any difference in scale will not affect he calculated angle of dip.

The **air base** is the line joining two air stations or he length of this line. The **line of flight** refers to the line of the air base or photo base.

C. Stereoscopy

Stereoscopy applied to vertical aerial photographs refers to the three-dimensional effect obtained by viewing two overlapping photographs (stereo pair) simultaneously, one with each eye. The position of the eyes corresponds to the original perspective centers of the photographs. The distance between the eyes corresponds to the distance between the perspective centers (or camera station), which distance in space is known as the air base.

The stereoscope is the instrument used for viewing the stereo pair. Two general types of stereoscopes are commonly used—the mirror type which allows full view of the overlap area of the photographs but which gives no magnification; and the lens type stereoscope which allows only part of the overlap area to be viewed from one position of the stereoscope (without partially lifting the overlapping photograph), and which gives magnification. Because the upper and lower points of a dip slope or bedding trace can be located more precisely using the lens type stereoscope, this type is recommended for use with the calculations of this paper.

D. Radial Line Principle

All points on the vertical aerial photographs are seen in perspective. However, the photo center is unique in that its position remains unchanged regardless of change in scale. Consequently, the photo center is the only point around which true horizontal angles can be measured in a normal manner. All other points lie on the photograph in a true angular position from the center. Moreover all other points except those on a datum plane are displaced radially from the photo center through the point. A **datum plane,** by definition and construction, is an imaginary plane passing through any arbitrary elevation on the ground, and above which the height of the airplane is measured. Points lying higher than the datum plane appear farther outward from the photo center than they would were they on the datum plane, and lower points appear closer to the center (fig. 1). If the position of the datum plane is placed arbitrarily passing through the lower point (l) on a bed or dip slope, and considering only the upper and lower points, all radial displacement by definition takes place at the upper point (u), and none at the lower.

E. Parallax

Parallax is the term used to denote the optical displacement of one object with relation to another. The parallax on vertical aerial photographs is restricted by definition to the displacement parallel to the line of flight. Absolute parallax is defined as "the algebraic difference parallel to the line of flight of the distance of the two images of a given object from their respective principal points".[2] For absolute parallax measurements, if the direction from the photo center to the point is towards the right, the measured distance is positive; if toward the left, negative. Therefore, where the stereo pair is properly oriented for stereoscopic vision to find the absolute parallax for either the lens or mirror type stereoscope, the distance from the photo center to a point on the right-hand photograph measured parallel to the line of flight is algebraically subtracted from the corresponding distance measured on the left-hand photograph of the stereo pair from the photo center to the same point. The resulting absolute parallax will generally approximate the photo base, and will be exactly the same as the measured photo base on one photograph if the transferred center lies at the elevation of the point whose absolute parallax is being measured.

F. Difference in Parallax

The difference in absolute parallax of any two points is termed dp. The difference in parallax may be measured directly from the stereo pair without first measuring the absolute parallax. Regardless of their position on the vertical photographs, any two points having the same elevation will have the same absolute parallax, and consequently no difference in parallax.

The difference in parallax may be measured in various ways. It may be scaled directly on the photograph with a rule, or may be measured with transparent overlay devices such as the parallax wedge or the floating line device, or with floating dot instruments such as the height finder, parallax bar, stereo-comparagraph, and contour finder, or with the various types of mechanical plotting devices.

Two methods are presented in this paper—the first, a directly scaled distance on a transparent overlay giving a measurement to the closest 0.1 millimeter, and the second which utilizes the height finder employing the floating dot system giving a measurement to the closest 0.01 millimeter. The transparent overlay is faster and easier to use than the height finder, although it is not as precise. It can be used, however, for most cases of dip determination. The use of the height finder is recommended in cases where a more precise measurement of the difference in parallax (dp) is needed (sec. VA2c).

G. Photo Base

The **measured photo base** (fig. 4) as used in this paper is defined as the measured distance on either photograph of the stereo pair between the photo center and the transferred center. This distance will be different on each of the photographs except in the case where the photo center and the transferred center are at the same elevation. The **adjusted photo base** (b) as used in this paper is defined as the distance the measured photo base would have been had the transferred center been at any arbitrary elevation or datum plane. For the calculations of this paper, the adjusted photo base is based on either the elevation of the upper (b_u) or lower (b_l) point. In the special case where the transferred center lies at the same elevation as l (or u), the measured photo base b_l (or b_u) needs no correction. In all other cases, the correction to be applied to the measured photo base scaled directly on a single photograph is the difference in parallax between the transferred center and the lower point

[2] American Society of Photogrammetry, Manual of photogrammetry, New York, Chicago, Pittman Publishing Corp., 1944.

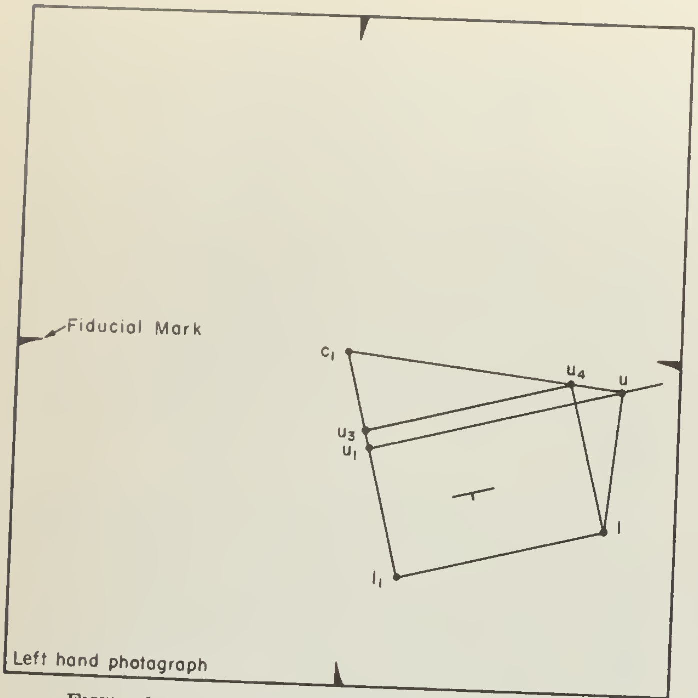

FIGURE 1. Construction to show true horizontal distance beween u and *l*.

EXPLANATION OF FIGURE 1

The figure represents the plan view of the left-hand photograph of the stereo pair, showing the construction lines necessary for obtaining the corrected horizontal distance between u and *l*, as described in Section IIIB and D.

The following are definitions and explanations of the various lines and points:

- u — the photo position of the upper point of the dip slope or bedding trace.
- l — the photo position of the lower point of the dip slope or bedding trace.
- ul — is in the direction of dip under the stereoscope.
- u_4 — the corrected horizontal position of u, related to the datum plane passing through *l*.
- c_l — the photo center of the left-hand photograph.
- l_1 — the intersection of a strike line projected through *l*, and a dip line projected through $c_l l$. The intersection is at the same elevation as *l*.
- u_3 — the intersection of a strike line projected through u_4, and a dip line projected through $c_l l$. This intersection is at the same elevation as *l*.
- u_4u — total net radial displacement of u in relation to *l*.
- u_3u_1 — net displacement in direction of dip of u in relation to *l*.
- $c_l l_1$ and $u_4 l$ — are construction lines drawn geometrically at right angles to the strike.

in the case of b_l; and the difference in parallax between the transferred center and the upper point in the case of b_u.

The factor of (b_l + dp) (the adjusted photo base based on the elevation of *l* plus the difference in parallax) as used in the equations of this paper is equivalent to the adjusted photo base (b_u) based on the transferred center being at the elevation of u (i.e., equivalent to the datum plane passing through u). Consequently, the measured photo base should be adjusted directly to the elevation of u, and this measurement (b_u) substituted for the factor (b_l + dp), thereby eliminating a small amount of calculation.

H. Geometrical Relationships

The fundamental equation upon which all calculations in this paper are based, is as follows:

$$\frac{u_1u_3}{c_lu_1} = \frac{dp}{b_l + dp} = \frac{dh}{f} = \frac{dH}{H}$$

(Equation I)

These terms are defined in explanations for figures 2 and 3.

This equation is derived in part from similar triangles shown on figures 2 and 3. On figure 3 by construction of similar triangles shown jkc_r and ku_1u_3, the following relationship is obtained:

$$\frac{u_1u_3}{jk} = \frac{u_1u_3}{c_lu_1} = \frac{dp}{b_l + dp}$$

Equation I is also derived in part from figure 2 from one set similar triangles (lensC_1U_1) and ($U_5U_3U_1$) which can be shown by construction to be similar to another set of similar triangles (lensc_1u_1) and ($u_5u_3u_1$) as shown by the following relationships:

$$\frac{u_1u_3}{c_1u_1} = \frac{U_1U_3}{C_1U_1} = \frac{dh}{f} = \frac{dH}{H}$$

I. Measurement of Difference in Height (dh)

Both the difference in height between u and *l* (in the geometry of the photograph) and the adjusted horizontal distance between them are necessary to solve for the angle of dip trigonometrically. This distance (dh) is a theoretical vertical distance which cannot be identified anywhere on the aerial photographs. However, its relationship to the photo points and ground points is shown in equation I.

From equation I and from the given equality (Sec. IIG) of $b_l + dp = b_u$ the following equation is derived.

$$dh = \frac{(dp)\,f}{(b_l + dp)} = \frac{(dp)\,f}{b_u}$$

(Equation II)

To solve for dh in equation II, the difference in parallax between u and *l*, and the adjusted photo base (either b_u or b_l) must be known, as well as the focal length (f).

The absolute difference in height (dH) between U and L (fig. 2) may be calculated from the following equation (derived from equation I) in cases where the height (H) of the airplane above the lower point of the dip slope or bedding trace is known:

$$dH = \frac{(dh)\,H}{f} = \frac{(dp)\,H}{(b_l + dp)} = \frac{(dp)\,H}{b_u}$$

However, this distance is not needed for the calculations presented in this paper.

J. Measurement of Horizontal Distance

Considering the lower point (*l*) to be on the datum plane, the upper point (u) has been displaced in relation to *l*, depending upon the difference in height (dh) between these two points. It is possible to adjust for this displacement by measuring the total net radial displacement at u by the methods described in section IIIB and D. The corrected horizontal distance obtained is the distance at right angles to the strike from *l* to the adjusted posi-

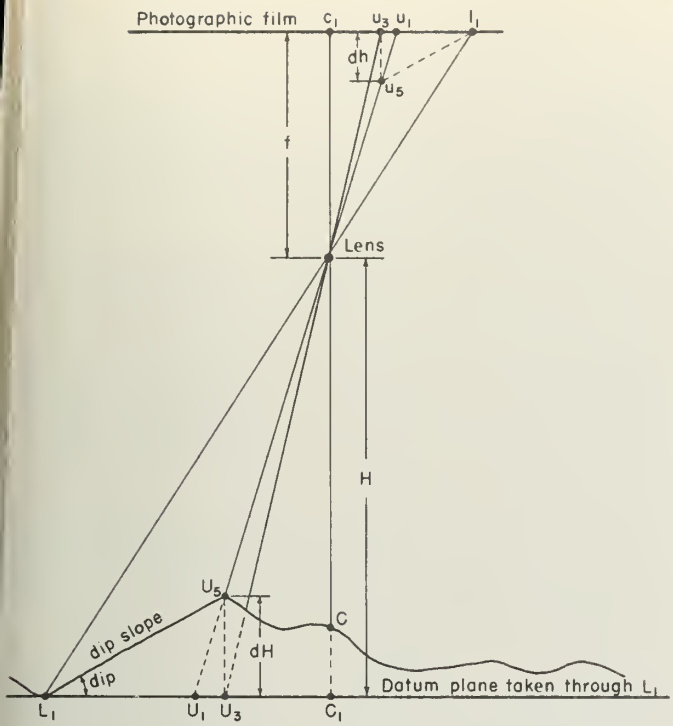

FIGURE 2. Vertical section along line c_1l_1 to show relationship of ground points to photo points.

EXPLANATION OF FIGURE 2

This plate represents a vertical section along line c_1l_1 (Figure 1), and shows the relationship between the similar triangles of the ground to those of the photograph.

The following are definitions and explanations of the various lines and points. Upper case letters refer to the ground points; lower case letters refer to points on the photograph.

U_3U_5 or dH	the difference in height between L_1 and U_5.
u_3u_5 or dh	the difference in height between l_1 and u_5.
H	the height of the airplane above the ground (datum plane).
f	the focal length of the camera lens.
C_1	the point on the datum plane of the ray passing vertically through the optical center of the camera lens.
c_1	the photo center of the left-hand photograph of the stereo pair.
u_3u_1	the radial displacement of u_5 due to difference in elevation between l_1 and u_5.

tion of u. The relationship of this corrected horizontal distance to the photo positions of u and l is shown by line u_3l_1 on figure 3.

K. Possible Sources of Error in Photogrammetric Dip Calculations

1. Tilt

Tilt is potentially the largest source of error in dip calculations. In commercial aerial photography, the absolute tilt on any single photograph is generally less than 1° and rarely as much as 3°, and the relative tilt between two adjacent photographs is rarely as much as 5°. Many variables enter into the problem of the effect by tilt on the dip calculations. The direction of tilt of the two photographs of the stereo pair relative to each other is significant. That is, if the two directions of tilt parallel each other the effect will be less than if the directions are not parallel, having a maximum effect when the directions of tilt of the two photographs are in opposite directions. Nevertheless, a small amount of tilt may considerably affect the dip calculations, especially as the direction of tilt more closely approaches the direction of the line of flight, and as the direction of dip more closely approaches the direction of tilt. Both relative and absolute tilt can affect the calculated dip. These relationships have been analyzed graphically, and are discussed in fuller detail in section VA6.

Tilt can be corrected as mentioned in section IIA. However, this involved correction is seldom made because the average tilt will allow an approximately correct dip calculation to be made.

2. Difference in Altitude of the Airplane at Two Adjoining Air Stations

Generally, the difference in altitude of the airplane at the two air stations is small in relation to the height of the airplane above the ground, and has little effect upon the dip solutions. However, this factor can be corrected at the same time the correction for tilt is made.

3. Unadjusted Photo Base

The net effect in the final dip result of adjusting the measured photo base to that of the elevation of the lower (l) or upper (u) point is small (generally less than 2 degrees), except in those cases where the difference in elevation between the transferred center and the point is considerable. However, the simple correction as described in section IIIB should always be applied to attain the highest accuracy possible.

4. Improper Alignment of the Photographs

This applies only to the measurement of the difference in parallax using the height finder. If the two photographs of a stereo pair are not properly oriented in regard to the line of flight, this measurement will be worthless. Because parallax, by definition, is measured in the direction of the line of flight, any apparent difference in parallax measured on incorrectly oriented photographs does not represent the true difference in parallax. Moreover, a slight error in alignment may give a relatively large error in the measurement of the difference in parallax.

5. Lens Distortion

This factor has no appreciable effect on measurement made to the closest 0.01 millimeter (as in the case of the difference in parallax) on the photographs.

6. Negative and Paper Distortion

Distortion of properly-handled negatives is negligible. However, distortion of untreated, single-weight positive paper prints may be of sufficient magnitude to affect direct measurements on the photograph. To avoid this, a

non-distortion paper which is waxed on the back to prevent moisture penetration should be used.

7. Incorrect Direction of Strike and Dip

It is essential that the geologist be able to recognize dip slopes and bedding traces. If the strike and dip are plotted carefully, the difference between the plotted directions and the true direction generally will be insignificant, except possibly in cases of low dip, or in cases where long strike or dip construction lines are necessary (section VA4).

8. Accuracy Possible in the Measurements

Measurements scaled on the photographs or on a transparent overlay made to the closest 0.1 millimeter, and the micrometer reading on the height finder made for the difference in parallax to the precision of 0.01 millimeter, will give surprisingly accurate dip results (sec. VA2). The longer the horizontal distance between the upper and lower points in the direction of dip, and the greater the difference in height between these two points, the less will be the error in the final dip calculations arising from small inaccuracies in the photo measurements.

III. APPLICATION OF THEORY TO TRIGONOMETRIC CALCULATION OF DIP

A. General

The two measurements necessary for the trigonometric calculation of dip are the adjusted horizontal distance (l_1u_3 of fig. 3), and the difference in height (dh of equation II and fig. 3), as shown in the following equation:

$$\text{tan angle dip} = \frac{\text{difference in height}}{\text{adjusted horizontal distance}}$$

substituting, we have

$$\text{tan angle dip} = \frac{(dh)}{l_1u_3} = \frac{(dp)\ f}{l_1u_3\ (b_l + dp)} = \frac{(dp)\ f}{l_1u_3\ (b_u)}$$

(Equation III)

This is the equation to use for the calculation of dip.

B. Procedure Step by Step

1. General

Two cases are presented here; the first is the measurement of the inclination of a dip slope, and second, the dip of strata exposed as bedding traces. Both cases are significant to geologists, but generally only the first of significance to other workers.

2. Measurement of the Inclination of a Dip Slope

The pocket stereoscope should be used in steps b, c, and d.

a. Locate carefully and mark the photo center of each photograph of the stereo pair at the intersection of lines joining opposite fiducial marks (fig. 1).

b. Carefully locate and mark with a needle point the point on each photograph of the stereo pair corresponding to the center point of the other photograph. This point is called the transferred center (tc_l or tc_r).

c. Using the stereoscope, locate and mark on the right-hand photograph two well-defined points, as far apart as possible on a slope, one directly down dip from the other.

d. Transfer and mark with a needle point these two points to the left-hand photograph.

e. Place on the right-hand photograph a transparent sheet of acetate approximately the same size as the photograph on which a straight line is ruled across the center on the underneath smooth side. Orient this transparency so that the line passes through both the photo center and transferred center.

f. Mark with a sharp-pointed pencil on this transparency overlay the three points corresponding to the photo center and upper and lower points.

g. Place the transparent overlay on the left-hand photograph, oriented so that the ruled line on the transparency passes through both the center point and the transferred center, and so that the upper point marked on the transparency coincides with the upper point on the left-hand photograph.

h. Mark on the transparency with a sharp pencil point, the points corresponding to the photo center and the lower point of the left-hand photograph. The distance from the photo center to that of the previous center as marked on the transparency is b_u.

i. Shift the transparency so that the lower point marked on the transparency from the right-hand photograph directly overlies the corresponding point on the left-hand photograph, and so that the ruled line still passes through the photo center and transferred center.

j. Mark on the transparency the points corresponding to the photo center and the upper point of the left-hand photograph. The distance from the photo center to that of the right-hand photo center marked on the transparency is b_l.

k. The distance on the transparency between either the two points marked for the upper point, or between the two points marked for the lower point is the difference in parallax (dp). This distance should be measured and averaged to the closest 0.1 millimeter.

l. Measure on the transparency the distance from the photo center of the right-hand photograph to the first-marked photo center of the left-hand photograph to the closest 0.1 millimeter. This is the adjusted photo base (b_u) based on the elevation of the upper point and is equal to the factor (b_l + dp).

m. Draw on the transparency a pencil line from the photo center marked from the right-hand photograph to the upper point marked from that photograph. (Actually this line need extend but several centimeters from the upper point towards the photo center.) Also draw the line from the second point marked for the photo center of the left-hand photograph to the other upper point marked on the transparency. The intersection of these two lines represents the corrected position of the upper point.

n. Measure the distance on the transparency from the lower point (marked from the right-hand photograph) and the corrected position of the upper point to the closest 0.1 millimeter. This distance is the corrected horizontal distance.

o. The tangent of the angle of dip may now be calculated, as shown in equation III, using the four factors of difference in parallax, adjusted photo base, corrected horizontal distance, and focal length. Actual calculations may be avoided if the nomogram of fig. 9 is used.

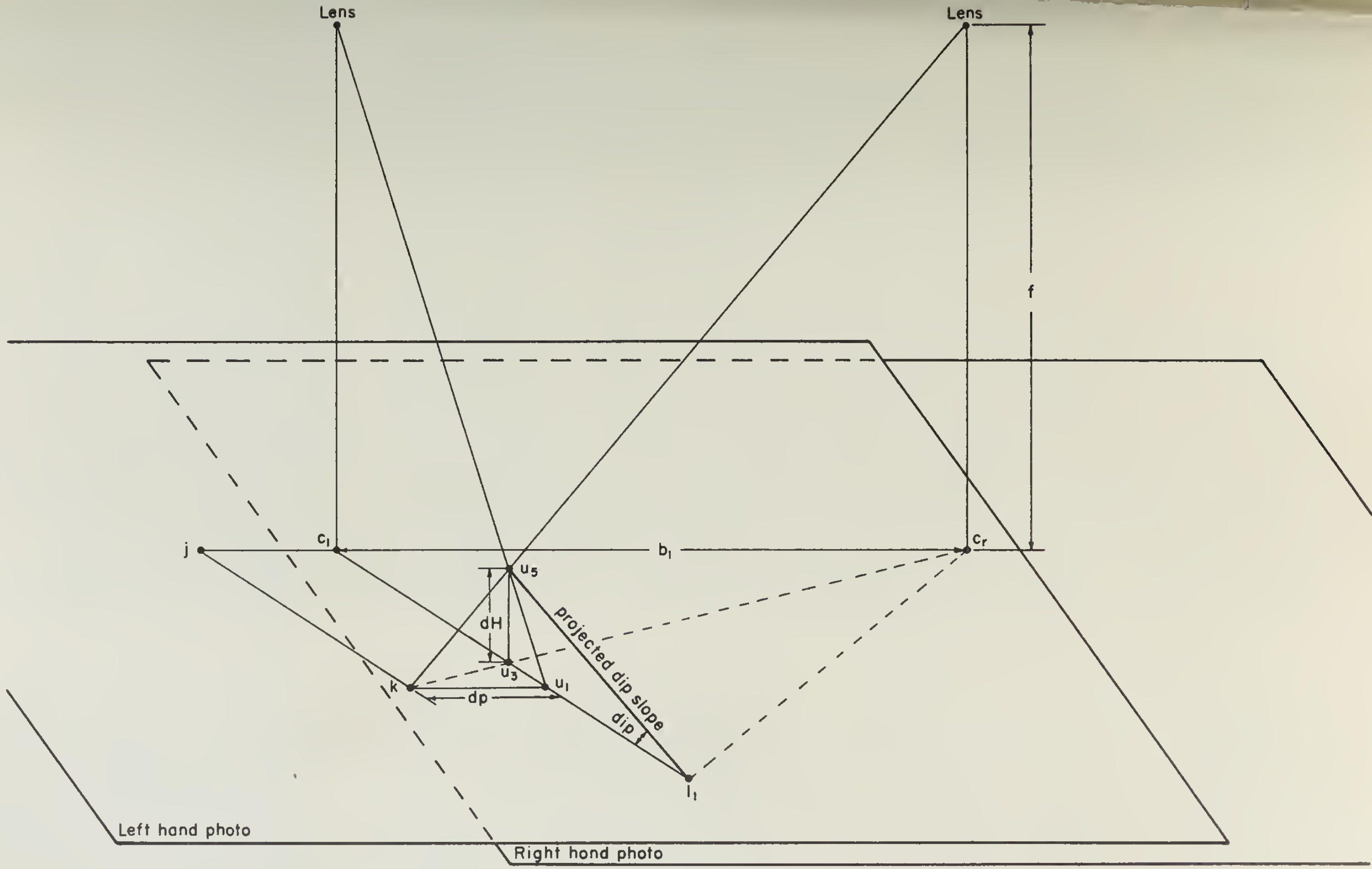

Figure 3. Isometric drawing to show three dimensional model of u_5 and l_1.

EXPLANATION OF FIGURE 3

This figure is an isometric drawing of the two photographs of a stereo pair, showing the spatial relationships of u_5 and l_1. These two points are chosen instead of u and l (Figure 1) because all displacement of u_5 is in the direction of dip, and the proof of the various relationships is greatly facilitated.

This figure emphasizes the relationships on the left-hand photograph.

The following are definitions and explanations of the various lines and points:

- c_l photo center of the left-hand photograph.
- c_r photo center of the right-hand photograph.
- b_l adjusted photo base, based on the elevation of l.
- f focal length of the camera lens.
- u_5 theoretical point in space, corresponding to U_5, of Figure 2.
- u_1 photo-position of u_5 on left-hand photograph.
- k photo position of u_5 on the right-hand photograph.
- u_3 corrected horizontal position of u_5 adjusted to the datum plane passing through l.
- u_3u_5 or dh the difference in height between l_1 and u_5.
- ku_1 or dp the difference in parallax between l_1 and u_5.
- u_3u_1 the net radial displacement in direction of dip of u_5 on the left-hand photograph, based on the datum plane passing through l.
- u_3k the net radial displacement in direction of dip of u_5 on the right-hand photograph, based on the datum plane passing through l.
- jc_l constructed equal and parallel to ku_1.
- jk constructed equal and parallel to c_lu_1.

3. Measurement of Dip of Strata Exposed as Bedding Trace

a. Same as steps **a** and **b** as described above.

b. Using the stereoscope, locate and mark with a needle point, well-defined upper and lower points on a bedding trace on the right-hand photograph. These points should be as close to each other in the direction of strike as possible, and at the same time, as far from each other in direction of dip as possible.

c. Same as steps **d** through **m**, as described above.

d. Under the stereoscope, on either photograph, place a small strip of clear acetate (about 1.5 centimeters by 7 centimeters on which a fine ink line has been ruled lengthwise), oriented so that the line passes through the lower point, and parallels the strike. Fix in place on the photograph by scotch drafting tape.

e. Lay the transparency on the same photograph, oriented so that the ruled line passes through the photo center and transferred center; if the right-hand photograph is used, so that the photo center points coincide; if the left-hand photograph, so that the photo center points are oriented as in step **i**, as described above.

f. Measure on the transparency the distance at right angles from the line passing through the lower point to the corrected position of the upper point. This is the corrected horizontal distance.

g. Calculate the angle of dip as described in step **o** above.

C. Alternate Procedures to Measure the Difference in Height (dh)

1. General

Alternate procedures for determining the difference in height (dh) between the upper and lower points depends upon a different method of measuring the difference in parallax and the adjusted photo base, although the same equation III is used for the final calculation.

a. Height Finder Used to Measure the Difference in Parallax. The Abrams height finder is the only instrument described in this paper for measuring instrumentally the difference in parallax, because it is simple, small, accurate, uses the magnifying lens-type stereoscope, and is generally available.

For any method of instrumental measurement of difference in parallax, the two photographs of the stereo pair must be oriented as precisely as possible in relation to the line of flight. This is done as described in the following steps:

i. Place a thin strip of clear acetate about 1.5 centimeters wide on which a thin ink line has been ruled across the right-hand photograph so that the line passes through the photo center and the transferred center marked from the left-hand photograph. This strip should extend completely across the photograph, and in most cases, will not pass through the other transferred center. Fix in place on the photograph by scotch drafting tape. (The acetate strip has the advantage of not marking the photograph, of bearing a line that is always thin and straight and of being easily adjusted.)

ii. Place a similar strip on the left-hand photograph oriented in a similar manner, and fix in place.

iii. Place one of the photographs of the stereo pair on the desk top so that the ruled line of the acetate strip will line up with a fine line already ruled across the desk top.

iv. Place the other photograph in approximately the correct position for use with the pocket stereoscope so that the ruled line of the acetate strip will line up with the ruled lines of both the first photograph and the desk top.

v. Using the stereoscope, shift one photograph until stereoscopic vision is obtained, keeping the ruled lines in position.

After the stereo pair is properly oriented as described above, the floating dots of the height finder are made to fuse first at the lower point, and then at the upper point. The difference in micrometer readings will be the difference in parallax (dp) between these points. The average difference of several sets of micrometer readings (four or five usually are necessary and sufficient) made to the closest 0.01 millimeter should be used as the average difference in parallax in the equations of this paper.

b. Height Finder Used to Obtain Adjusted Photo Base. In this method, the height finder is used to measure the difference in parallax between the transferred center and the lower point. This difference in parallax should be added to the measured photo base in cases where the elevation of the transferred center is lower than the lower point; where higher, the difference in parallax should be subtracted. This adjusted photo base (b_l) is based on the elevation of the lower point. To this figure should be added the difference in parallax between the upper and lower points to obtain the factor (b_l + dp).

However, to adjust the measured photo base directly to the datum plane passing through the upper point, the difference in parallax between the transferred center point and the upper point should be measured. The measured photo base should be adjusted by the amount of this difference in parallax, as described above, to obtain the adjusted photo base (b_u) based on the elevation of the upper point, and which is equivalent to the factor (b_l + dp).

D. Alternate Procedures to Measure the Corrected Horizontal Distance

1. Graphic Method

This method is based on the fact that a line drawn under the stereoscope in the direction of dip will not be at right angles to the line of strike plotted on a single photograph (fig. 1), except in the special case of the stereoscopic dip line passing through the photo center. In contrast, a strike line drawn under the stereoscope will have the same direction as the strike line drawn on a single photograph.

Two cases are considered: the first in which u and l are in the direction of dip on the stereo model, and the second in which they are not. The first case needs but three construction lines and one photo measurement. The detailed procedure to be used in the first case is as follows:

a. A transparent acetate strip on which a fine ink line is ruled, is placed on the photograph so that the line passes through the photo center and the upper point, and fastened in place with scotch drafting tape.

b. Another similar strip is placed on the same photograph, oriented so that the line passes through the lower point in the direction of strike, and is also fastened in place.

c. A measurement is made on the photograph at right angles to this strike line from the lower point to the radial line passing through the upper point. This distance (lu_4 of fig. 1) is the adjusted horizontal distance between u and l, and should be measured to the closest 0.1 millimeter.

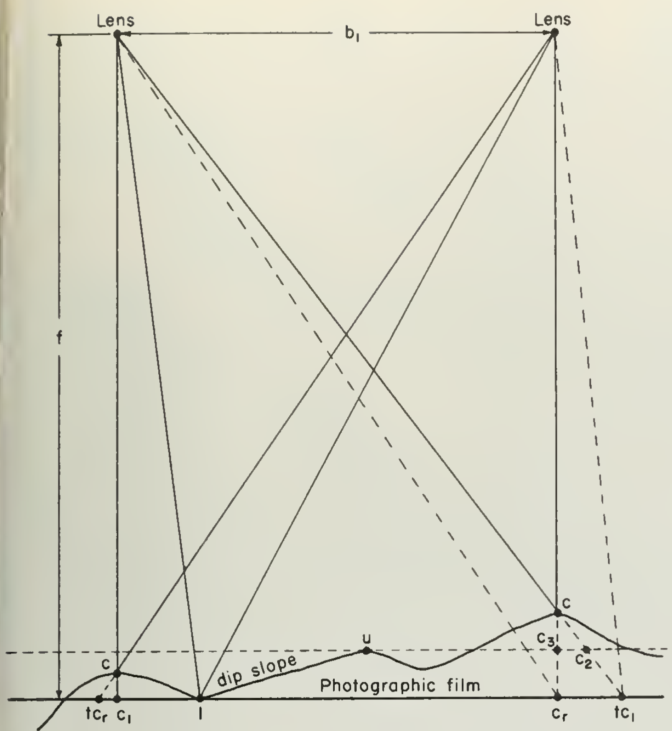

Figure 4. Vertical section along photo base.

EXPLANATION OF FIGURE 4

This figure represents a vertical section along the photo base (line of flight), showing the adjustment of the measured photo base by the amount of the difference in parallax between the transferred center and l. This is based on the left-hand photograph of the stereo pair.

The following are definitions and explanations of the various lines and points:

- c_l photo center of the left-hand photograph.
- c_r photo center of the right-hand photograph.
- tc_l transferred center on the left-hand photograph.
- tc_r transferred center on the right-hand photograph.
- c_rtc_r difference in parallax between tc_l and l.
- c_lc_r adjusted photo base, based on l. This is the distance the measured photo base on the left-hand photograph would have been if c_l were at the elevation of l.
- c_2c_3 difference in parallax between c_2 and u.
- f focal length of the camera lens.

In the second case, where l and u are not on the line of dip as seen under the stereoscope, the procedure is slightly different.

a. An acetate strip similar to that used above is placed on the photograph so that the line passes through u in the direction of strike, and is fastened in place with scotch drafting tape.

b. Another similar strip of acetate is so placed that the line passes through l in the direction of dip (seen under the stereoscope), intersecting the strike line.

c. The intersection of these two lines will be equivalent to the position of u in the first case described above. The method already described above can now be used for finding the corrected horizontal distance.

In this graphic method, the distance between l and u_4 can be scaled more accurately in those cases where the radial line through u approaches the direction of strike. The inaccuracy becomes potentially greater as the radial line through u approaches the direction of dip (i.e., at right angles to the strike). This is so because the point of intersection of the radial line c_lu and the line through l at right angles to the strike (fig. 1) can be located more precisely as their angle of intersection approaches 90 degrees. If the radial line through u is in the direction of dip under the stereoscope, the corrected horizontal distance cannot be solved for graphically on that photograph, because the two lines will be coincident and there will be no intersection. Therefore, the one photograph of the stereo pair which will give the more accurate measurement as just described must be chosen.

2. Radial Displacement Method

This method which has been described by L. J. Desjardins [3] combines a graphic and a calculated solution to obtain the corrected horizontal distance (l_1u_5) between the upper and lower points. The method as originally described consists of calculating the total net radial displacement at the lower point due to difference in elevation between the upper and lower points. As modified to fit the geometry developed in this paper, all the displacement is considered to be at the upper point, and the following equation is used (see fig. 2):

$$d_u = u_3u_1 = \frac{c_lu_1\ (dp)}{(b_l + dp)} = \frac{c_lu_1\ (dp)}{b_u}$$

where d_u is the radial displacement of the upper point due to difference in elevation between the upper and lower point.

c_lu_1 is the photo distance from the photo center to the upper point.

dp is the difference in parallax between the upper and lower points.

b_l is the adjusted photo base, based on the elevation of the lower point.

b_u is the adjusted photo base, based on the elevation of the upper point.

The distance (d_u) is scaled on the photograph radially toward the photo center from the upper point, giving the corrected horizontal position of the upper point. If the upper and lower points are on the line of dip from each other, the distance from the lower point to the corrected position of the upper point will be the corrected horizontal position. If the two points are not on the line of dip, the lower point must be projected along the line of strike by a ruled transparent strip. A measurement normal to this line, from the line to the corrected position of the upper point, will give the corrected horizontal distance between the two points.

This method would become practical only if a nomogram were constructed to solve easily the above equation.

[3] Desjardins, L. J., Techniques in photogeology: Am. Assoc. Petroleum Geologists Bull., vol. 34, no. 12, pp. 2284-2317, 1950.

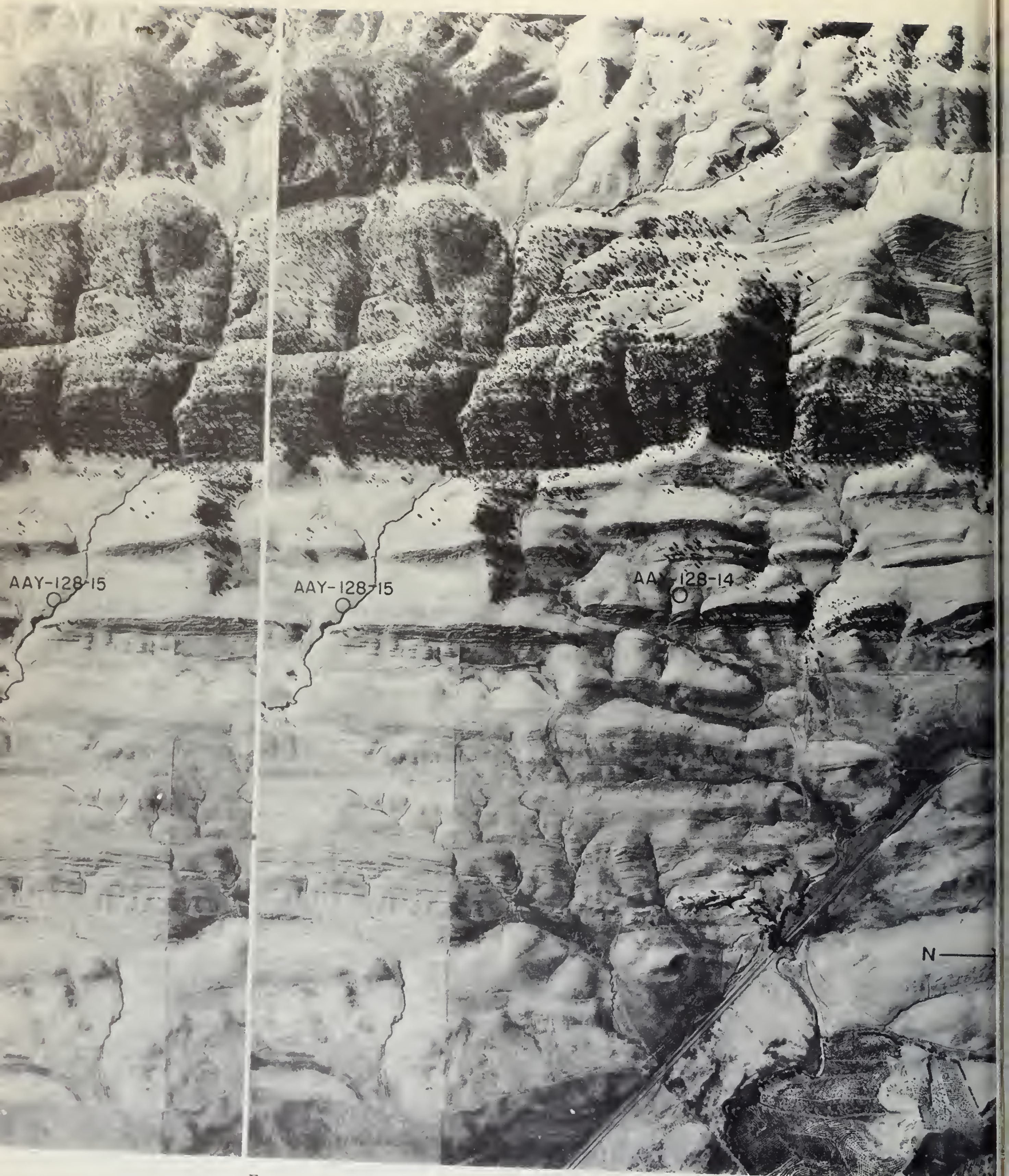

FIGURE 5. Stereogram, Lodoga quadrangle, Colusa County, California.

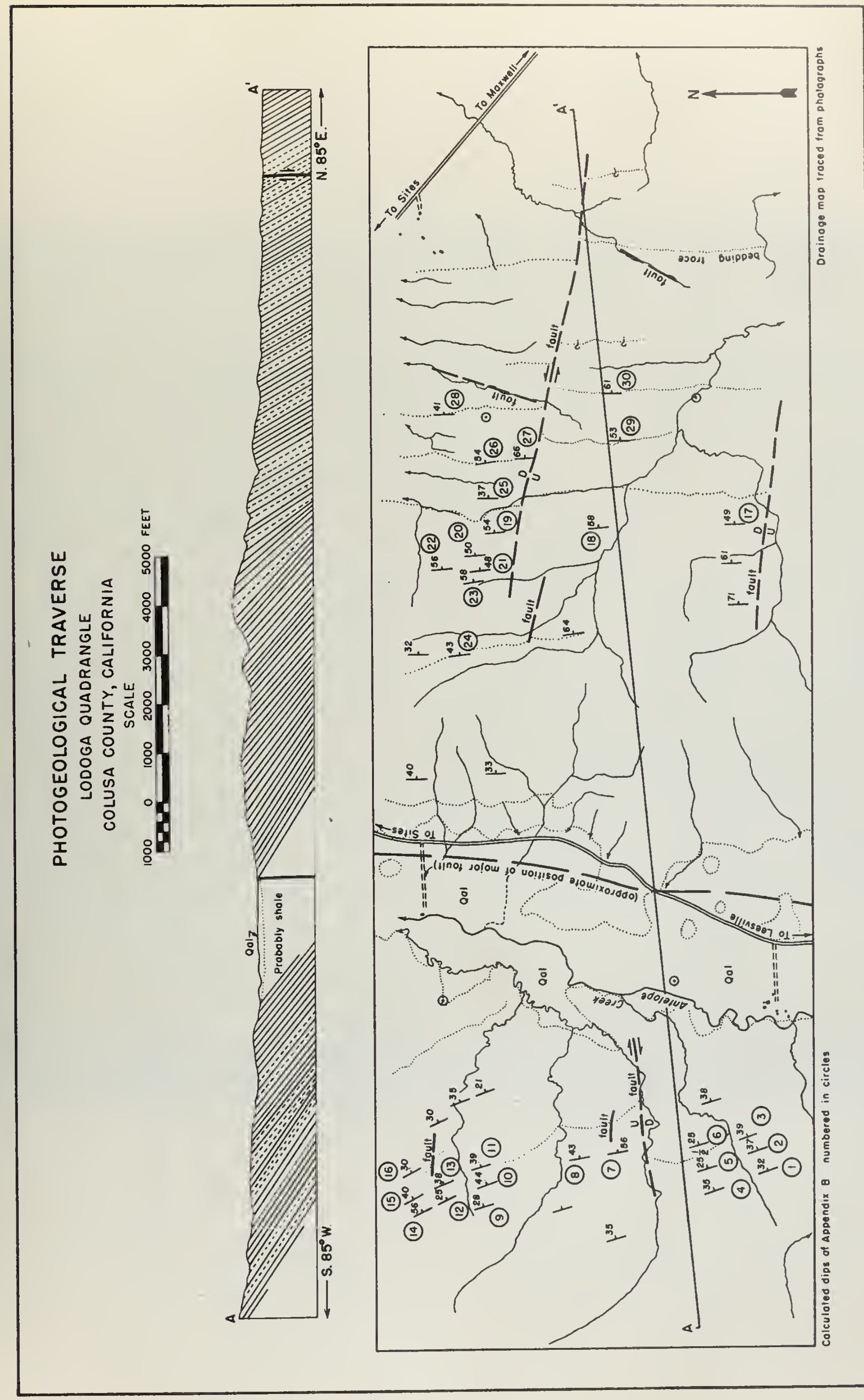

FIGURE 6. Photogeological traverse, Lodoga quadrangle, Colusa County, California.

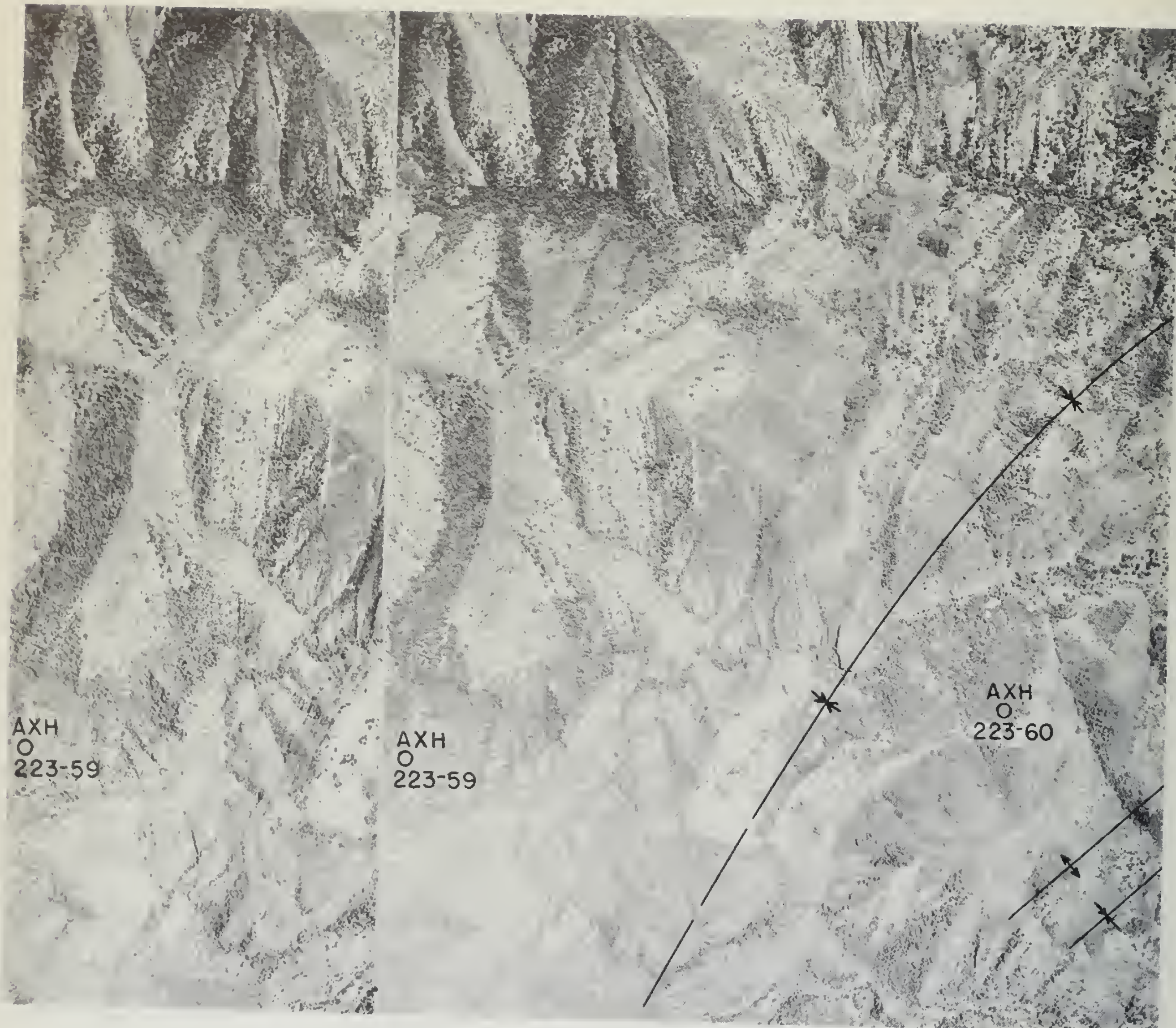

FIGURE 7. Stereogram, Nipomo quadrangle, San Luis Obispo County, California.

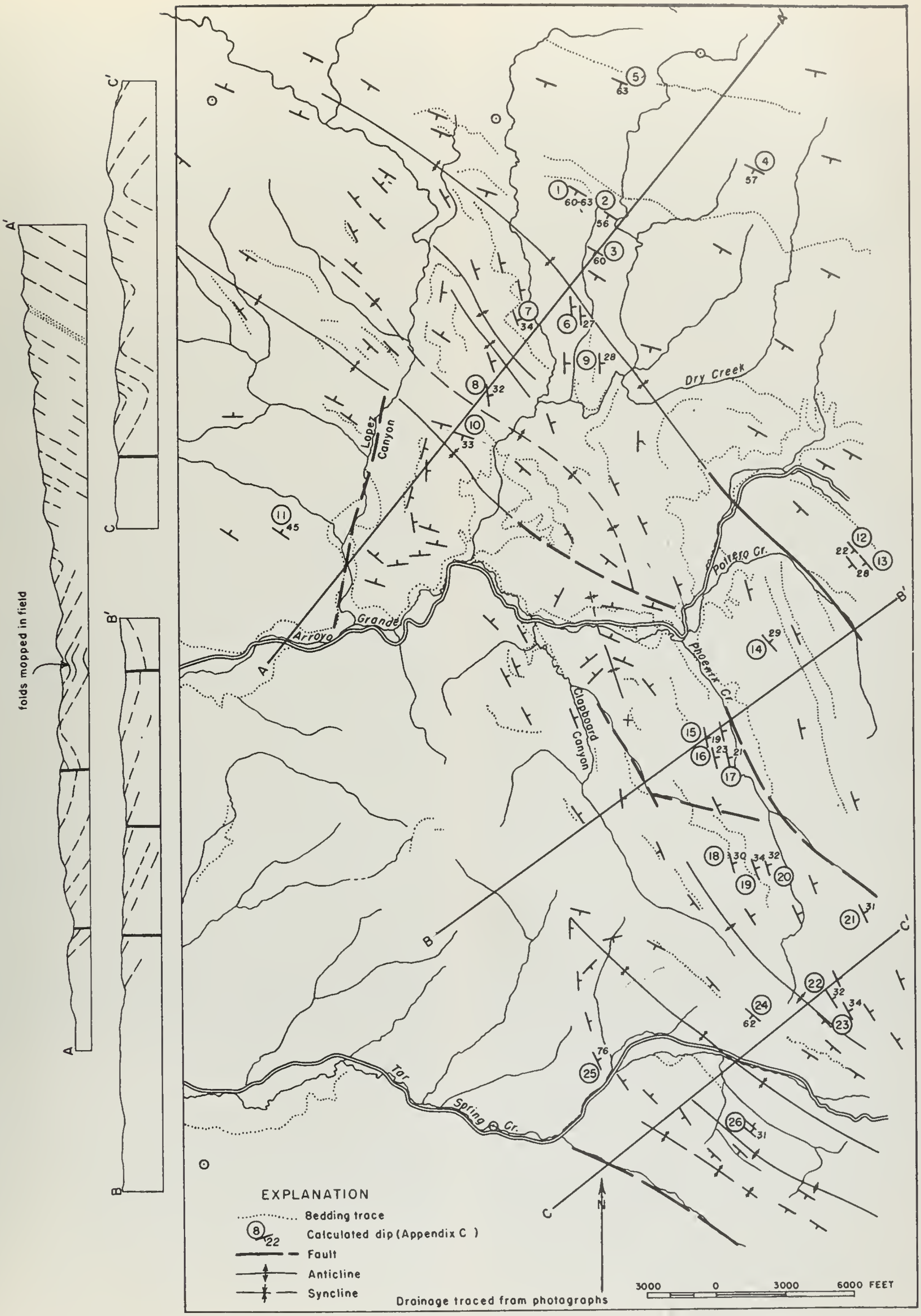

Figure 8. Photogeological interpretation of the northwest corner, Nipomo quadrangle, San Luis Obispo County, California.

IV. FIELD CHECKS OF PHOTOGEOLOGIC INTERPRETATION

A. Lodoga Quadrangle, Colusa County, California

1. General

A short photogeologic traverse was made in the Lodoga quadrangle (fig. 6) where both lithology and faulting were interpreted, and the dips calculated. Data for these calculations are included in table 1. The photographs are at the scale of approximately 1:20,000.

The regional strike here is approximately north, with east dips ranging from about 25° to 60° on the east limb of Sites anticline.[4] The rocks in this region consist of interbedded massive sandstone and well-bedded, poorly exposed shale of the Upper Cretacious Chico group. Several small cross faults are present, and a large strike fault borders the eastern side of Antelope Valley.

2. Dips

The dips measured for this traverse have been placed in four groups (table 1) of similar dips. Within any one of these groups, both the calculated and field observed dips vary considerably. However, the averages of the calculated and field dips within each of these groups correspond closely. For reasons explained below, in this specific area, no exact correlation of calculated dips with the dips observed in the field can be expected.

The difference in the dips observed in the field in any of the four groups may be due to any of the following factors: 1) minor flexing; 2) primary wavy bedding; 3) cross-bedding obscuring the true dip; 4) undetected slumping of outcrops; and 5) weathering of beds to planes simulating bedding surfaces. In large exposed cliff sections, the changes in dip due to minor flexing are readily apparent. In addition, the dip may be affected by bedding slippage, although this feature was not specifically noted in the field.

The difference in the calculated dips may be due largely to the relatively small measurements (sec. VA2) of the corrected horizontal distance and the difference in parallax, with which the accuracy of the measurements becomes more critical; and also to the effects of minor flexing.

3. Lithology

The photogeologic interpretation of interbedded shale and sandstone is based essentially on the presence of hard and soft beds having distinct topographic expressions. Furthermore, in this area the vegetation, which is generally denser in areas of harder rocks than of softer rocks, indicates porosity such as is commonly present in sandstone. Field checking corroborated the lithologic interpretation except in the case of several conglomerate beds which were found on both sides of Antelope Valley. Because these conglomerate beds have the same topographic expression as the sandstone beds, they could not be differentiated by photogeologic interpretation.

4. Faults

Cross faults in this traverse were interpreted from the offset of the well-defined sandstone ridges. The relative stratigraphic displacement at the general scale of the photograph can be calculated from the angle of dip of the offset beds and the corrected photo horizontal distance, which can be obtained by measuring to points of equal elevation. This photo distance converted to feet or meters at the average scale of the photograph will give the approximate absolute stratigraphic displacement of the fault.

The large strike fault shown on the east side of Antelope Valley has been interpreted from the different strike of the beds on either side of the fault.

Several small diagonal cross faults were interpreted from straight drainage lines at an angle to the usual drainage pattern.

5. Profile

One application of the transparent overlay method for measuring the difference in parallax can be used in drafting the profile of a line of cross-section, as that shown on figure 6. To obtain the relative difference in height between any two points along the cross-section, as for instance from a point on the flat valley floor to a high point, these two points may be considered as the lower and upper points of a slope. The procedure for finding the difference in height is the same as outlined in section IIIB2 (steps **a** through **j**, with the exception that in step **j** the photo center is not marked again). The difference in parallax (dp) and the adjusted photo base (b_u) can now be measured on the transparency (steps k and l). The relative difference in height can then be calculated from equation II:

$$dh = \frac{f\ (dp)}{b_u} \quad \text{(Equation II)}$$

The difference in height will be approximately at the scale of the photograph, and can be used directly in the profile section if this is made at the approximate scale of the photographs.

B. Nipomo Quadrangle, San Luis Obispo County, California

1. General

The area covered by photogeological interpretation lies in the northwest corner of the Nipomo Quadrangle (figs. 7 and 8). Several broad anticlines and synclines are well defined on the photographs which have a scale of approximately 1:22,000, and are easily mapped. One exception to this is a tight fold which was overlooked in the photogeological interpretation, but which was mapped during the field check of the area and indicated as such on figure 8. This example emphasizes the importance of field checking. In the southwestern part of this area where the tightly-folded strata are poorly exposed on the rolling grass-covered hills, no structural photo-interpretation could be made. In addition, probable structural complexities are only partly reflected in the topography in the central section.

2. Dips

The dips calculated from the photographs are generally within plus-or-minus 10 percent of the dip observed in the field. The dip of 22 degrees near Potrero Creek on the eastern flank of the syncline was measured on the photo from the top of the ridge to the valley floor. In the field, the bedding was found to be undulating and ranging from 10° to 30°—with no one true representative dip being available at the place of the calculated dip. It is believed that the calculated dip, in a case such as this, may give a more reliable average value than that obtainable in the field.

[4] Kirby, J. M., Sites Region: California Div. Mines, Bull. 118, pp. 606-608, 1943.

3. Lithology

The expression of the different lithologic units is not as clear-cut as in the case of the Lodoga quadrangle. Interbedded sandstone and shale of the middle and upper Miocene Monterey group, comprise the major part of the exposed rocks. However, by photogeological interpretation, these could not be distinguished from thin-bedded siliceous shales and cherts, massive friable sandstone, and arenaceous limestone. The light-colored soil derived from the shale, and which supports little vegetation, has a distinctive pattern on the photographs. However, on the ground, the shale appears to have no special lithologic characteristics.

4. Faults

Several faults have been interpreted based on abrupt termination of structural trends or specific beds. Although a small fault was questionably mapped from the photographs along Potrero Creek at the axis of a syncline, no field evidence for faulting was found.

V. CONCLUSIONS

A. Accuracy Possible

1. General

Although there are many variables in the calculations for the dip measurements, the general range in accuracy of calculated dips is within plus-or-minus 10 percent of the observed field dips. This figure has been obtained after two field problems were worked, and although the data is scant, it is indicative. To a large extent the accuracy depends upon the precision of the individual measurements, which in turn depends upon the magnitude of these measurements. Measurements of dips approaching horizontal or vertical may be generally less accurate than those dips in a middle range. This is so because dips close to horizontal generally have small differences in parallax, and dips close to the vertical have short corrected horizontal distances.

A higher degree of accuracy may be expected from a worker after he has become familiar with photogrammetric measurements. Specifically, the stereoscopic locating and transfer of points, and measurements made with the height finder become more accurate.

Furthermore, the accuracy of this photogrammetric method for calculating the angle of dip depends in part upon the sharpsightedness of the operator. That is, the smaller the difference in angular convergence of his lines of sight that he can detect, the more accurately can he operate the height finder or transfer points under the stereoscope.

The quantitative differences quoted below in section VA2 are based on a focal length of 8¼ inches (209.6 millimeters), but are of the same general magnitude for other focal lengths.

2. Effect of Measurements on Accuracy of Dip Calculations

a. The Adjusted Photo Base. This is the longest measurement to be made on the photographs, and need only be measured to the closest 1.0 millimeter. A difference of 1.0 millimeter in the measurement of the photo base will affect the final dip result by not more than half a degree in all cases except possibly where the measurements of the difference in parallax, adjusted horizontal distance, and the adjusted photo base are extremely large or small. However, because the adjusted photo base can be read easily to 0.1 millimeter on the transparent overlay, it is suggested this degree of precision be practiced even though it is not absolutely necessary.

b. The Corrected Horizontal Distance. This distance on the transparent overlay should be made to the closest 0.1 millimeter. The longer this distance, the less will be the difference in the dip result caused by the difference of 0.1 millimeter in reading the measurement. A difference of 0.1 millimeter in the range of approximately 5 millimeters will affect the final dip result by less than half a degree. However, in the range near 1.0 millimeter this same difference may affect the final dip result by as much as 2½ degrees, with increasing differences in dip result as the adjusted horizontal distance becomes smaller.

As indicated by the field check in the Lodoga quadrangle, if the adjusted horizontal distance is less than 0.7 millimeter, the final dip result will be generally less accurate than dips calculated with a larger horizontal distance. This figure of 0.7 millimeter is an arbitrary figure based on meager data, but it gives an idea of the general degree of magnitude of the lower limit of the corrected horizontal distance consistent with acceptable accuracy.

c. The Difference In Parallax. This distance should be measured from the transparent overlay to the closest 0.1 millimeter. Because in most cases, this is the shortest distance measured from the photographs, an error of 0.1 millimeter will have a greater effect upon the final dip result than the same error in other measurements. In one specific case solved for a given dip of 35 degrees, an error in measuring of 0.1 millimeter at the range of 2.0 millimeters affected the final calculated dip by 1½ degrees, whereas the same error in the range of 0.2 millimeter affected the dip by 9½ degrees. The greater the vertical distance between the upper and lower points, with the consequent larger difference in parallax, the less the final dip result will be affected by small errors in measuring the difference in parallax.

3. Transfer of Points

The upper and lower points must be transferred carefully from one photograph to the other, and then to the transparency. Any difference will be directly reflected in the measurement of the difference in parallax.

To check the accuracy of the stereoscopic transfer of points, a small inked circle of the same size can be spun around each of the two points. Under the stereoscope, these circles will appear to fuse and to float horizontally at the elevation of the point if the point has been transferred carefully.

4. Strike or Dip Projections

The longer a construction projection of either strike or dip, the less accurate may be the dip result. This was demonstrated on the Lodoga quadrangle traverse where several cases involving a projection of strike through the lower point of more than 5 millimeters showed less average accuracy than for cases involving shorter strike projections.

5. Scale of the Photograph

The average scale of the photograph is significant insofar as larger scales will show a longer photo distance for any specific ground distance. The importance of long

photo distances has been discussed above. Photographs having a scale of 1:20,000 or larger consequently are preferred over those having a scale of 1:30,000 or 1:40,000. In addition, with larger scales, more geologic interpretation can be made because of the greater detail apparent on the photographs. However, modifying the importance of the scale of the photograph for the amount of interpretation possible is the apparent difference of relief on the three-dimensional stereoscopic image seen under the stereoscope. This is governed by the angular field of the camera and the altitude of the airplane above the ground. Assuming the standard 60 percent overlap of two adjacent photographs along the line of flight, the minimum angular field of the camera should be about 40 degrees for photogeologic interpretation.

6. Tilt

Tilt may affect dip calculations appreciably. The calculated dip is affected by the following significant factors—the direction of tilt relative to the line of flight, the direction of tilt of the two photographs of the stereo pair relative to each other, the direction of dip relative to the direction of tilt, and the amount of tilt. Lesser factors are the focal length, the adjusted photo base, the difference in height between the upper and lower points, and the distance from these points to the photo centers of the stereo pair.

Either or both photographs of the stereo pair may be tilted. For a graphic analysis of the effect of tilt on the dip result, only relative tilt was considered; that is, one photograph remaining truly vertical, and the other photograph being tilted. In several test cases solved graphically, the following observations were made. Tilt in the direction of the line of flight has more effect upon the dip calculations than any other of the above single factors. Conversely, tilt at right angles to this direction generally has no appreciable effect. The adjusted photo base is the measurement generally most affected whereas the difference in parallax and the adjusted horizontal distance are affected but slightly. In addition, tilt will have more effect if the direction of dip parallels the direction of tilt rather than at right angles to it. In the graphic cases solved having a tilt of 3° in the direction of the line of flight, with the direction of dip paralleling this, in the range of dip from 20° to 60°, a maximum difference of dip result of 4° was noted (based on a focal length of $8\frac{1}{4}$ inches and an adjusted photo base of 82 millimeters).

The presence of relative tilt is suggested by the two following conditions: 1) the divergence of the position of one photo center from the usual uniform spacing of the photo centers along a nearly straight line of flight, and 2) the difference in the distance normal to the line of flight from this line to the same point on the two photographs of the stereo pair.

Specifications for commercial aerial photography generally require that the average tilt of the vertical aerial photographs for the entire mapping project be no more than 1 degree, that the maximum of any one photograph be no more than 3 degrees, and that the relative difference in tilt between two adjacent photographs not exceed 5 degrees. Therefore, except in certain unusual cases of maximum allowable tilt, the effect of tilt will generally be of little consequence, except possibly in cases of dips approaching the horizontal.

7. Buckling and Swelling of Acetate Sheet

This will be appreciable only on paper-thin acetate, where it may significantly affect measurements on the transparency. This can be avoided by using an acetate sheet of medium thickness.

8. Drafting Inaccuracies

This applies specifically to: 1) the permanent line ruled on the smooth underside of the transparency, 2) the two lines drawn on the transparency to the two positions of u from the two marked photo centers (sec. IIIB2m), and 3) the transfer of points from the photograph to the transparency. If careful work is done, errors due to drafting inaccuracies can be reduced to a negligible minimum.

B. Time Required for Calculations

A dip calculation on either a slope or bedding trace using the transparent overlay method (sec. IIIB) and the nomogram (fig. 9) can be made in about 10 minutes by a worker familiar with the procedure. If the height finder is used to measure the difference in parallax, a slightly longer time will be needed.

C. Comparison with Stereographic Projection Method of Dip Calculation

A graphical method of dip solution using a meridian stereonet and a translucent paper protractor has been developed by R. E. Wallace.[5] This method is unique in that the measurements can be made in some cases without using the stereoscope. The following distances or angles must be measured on each photograph of the stereo pair: 1) the distance expressed as an angle from the photo center to the intersection of two straight-line segments of a single bedding trace; 2) the azimuth from true north of a radial line from the photo center to this point; and 3) the angle between each of the two straight-line segments of a bedding trace with a true north line. With these measurements, the direction of strike and the angle of dip may be solved graphically using the stereonet and paper protractor.

This ingenious method, even though essentially a graphic solution, may be rather involved for geologists unfamiliar with the stereographic projection. Moreover, ground control or a base map are needed to plot the direction of true north on both photographs. Presumably, however, either an arbitrary north line or a line normal to the line of flight may be substituted for the direction of true north. If this substitution is made, the direction of the strike obtained will be directly related to the arbitrary north or to the normal to the line of flight, and not to true north.

This method cannot be used in the following cases: 1) where the bedding trace does not form an angle between two straight-line segments; and 2) on dip slopes. Because the trigonometric method is generally more applicable, it is recommended.

Tilt has less effect on the stereographic projection dip solution than on the trigonometric solution. No data are available on the effect of small errors in the angles between the bedding trace and true north. The time required for the stereographic projection solution is roughly the same as that for the trigonometric calculation.

[5] Wallace, R. E., Determination of dip and strike by indirect observation in the field and from aerial photographs: Jour. Geology, vol. 58, no. 3, pp. 269-280, 1950.

Table 1. Data for Dip Calculations—Lodoga Quadrangle

No.	Photograph no.	f	dp	lu_4	b_u	Dip	Remarks	Field dip
1	AAY 102–12(13)	209.6 mm	1.5 mm	6.2 mm	80.6 mm	32°	(same bed as #4)	35°
2	" " 12(13)	"	1.4	4.8	80.1	37°	(same bed as #5)	31°
3	" " 12(13)	"	1.1	3.55	80.0	39°	(same bed as #6)	32°
4	" " 12(13)	"	1.4	5.1	80.6	35°		36°
5	" " 12(13)	"	1.1	6.0	74.0	25½°		35°
6	" " 12(13)	"	0.9	4.8	73.6	28°		37°
	Average calculated dips 33° ±7°: average field dips 34° ±3°							
7	" 102–13(14)	"	0.9	1.7	73.9	56°		av. 41°
7	" " 13(14)	"	0.68*	1.7	73.9	48°		av. 41°
8	" " 13(14)	"	0.7	2.1	73.7	43½°	(same bed as #7)	av. 31°
9	" " 13(14)	"	0.5	2.6	74.2	28½°		av. 42°
10	" " 13(14)	"	1.0	2.9	74.0	44½°		35°–53°
11	" " 13(14)	"	0.65	2.25	73.6	39°		34°–43°
12	" " 13(14)	"	0.5	3.0	73.8	25°		av. 40°
13	" " 13(14)	"	0.9	3.3	73.8	38°		37°
14	" " 13(14)	"	1.0	1.9	73.4	56°	(same bed as #10 & #12)	39½°
14	" " 13(14)	"	0.9*	1.9	73.4	53°		39½°
15	" " 13(14)	"	1.1	3.75	73.7	40°	(same bed as #11 & #13)	av. 37°
16	" " 13(14)	"	0.4	2.0	72.8	30°		36°
	Average calculated dips 42° ±17°: average field dips 39° ±14°							
17	" 128–14(15)	"	1.3	3.6	66.9	48½°		av. 49°
17	" " 14(15)	"	1.7	4.6	66.8	49°		av. 49°
18	" " 14(15)	"	1.45	2.75	67.8	58°		43°
19	" " 14(15)	"	1.1	2.3	74.0	54°		av. 51°
20	" " 14(15)	"	1.0	2.5	69.0	50½°		55°
21	" " 14(15)	"	1.7	4.6	69.6	48°		48°
22	" " 14(15)	"	1.65	3.3	69.0	56°		55°
23	" " 14(15)	"	1.1	2.25	64.6	58°		not checked
24	" " 14(15)	"	1.3	4.1	69.6	43½°		av. 49°
	Average calculated dips 51½° ±8°: average field dips 50° ±7°							
25	" " 14(15)	"	0.6	2.5	67.1	37°		av. 58°
26	" " 14(15)	"	1.4	3.2	67.4	53½°	(poor)	av. 45°
26	" " 14(15)	"	1.4	3.1	67.5	54½°	(poor)	av. 45°
27	" " 14(15)	"	0.7	0.95	66.9	66½°	(poor)	av. 45°
28	" " 14(15)	"	0.5	1.8	66.8	41°		av. 40°
29	" " 14(15)	"	1.8	4.2	67.1	53°		50°
30	" " 14(15)	"	1.7	2.9	66.5	61°		49°–62°
	Average calculated dips 52° - 14½°: average field dips 50° + 12°							

* Height finder used.

Table 2. Data for Dip Calculations—Nipomo Quadrangle

No.	Photograph no.	f	dp	lu_4	b_u	Dip	Remarks	Field dip
1	AXH 223–21(22)	209.6 mm	4.8 mm	5.25 mm	93.5 mm	63°		
1	" " 20(21)	"	4.4	5.9	86.4	60½°		
2	" " 20(21)	"	3.35	5.6	82.3	56½°	60° ±3½°	(56°, 59°, 59°, 59°, 61°)
3	" " 20(21)	"	1.8	2.6	81.0	60°		av. 59° + 3°
4	" " 21(22)	"	1.4	2.0	94.9	57°		
5	" " 21(22)	"	2.9	3.1	94.1	63½°		
6	" " 60(61)	"	0.85	4.6	77.4	26½°	hill slope	hill slope 26° - 28°
7	" " 20(21)	"	1.35	5.3	78.8	34°	dip slope	34°
8	" " 60(61)	"	2.15	9.0	78.3	32°	hill slope	not checked
9	" " 60(61)	"	2.05	10.2	78.0	28°		(not good) 28°
10	" " 61(62)	"	2.15	7.9	85.5	33°	bed	(on next ridge) av. 39°
11	" 224 14(15)	"	1.8	3.8	96.0	45°		warped 30° - 60°
12	" 223 18(19)	"	0.81*	5.4	80.5	22°		wavy 10° - 31°
13	" " 18(19)	"	0.46*	2.0	89.5	28°		
14	" " 18(19)	"	1.0	4.7	80.5	29°		(poor) (28° - 38° - 38°)
15	" " 18(19)	"	1.85	13.8	79.1	19°		
16	" " 18(19)	"	1.6	10.0	79.0	23°	21° average	(not good) (20° - 26°)
17	" " 18(19)	"	1.6	11.0	78.6	21°		
18	" " 16(17)	"	2.05	8.5	85.1	30°		
19	" " 16(17)	"	2.5	9.1	84.8	34°	32° ±2°	35°, 34°, 33°, 31°, 30°
20	" " 16(17)	"	1.85	7.25	84.2	32°		av. 33° ±3°
21	" " 15(16)	"	1.6	7.1	85.0	31°		34°
22	" " 15(16)	"	1.0	4.1	84.1	31½°	33° ±2°	(projected) 33° ±3°
23	" " 15(16)	"	1.6	5.7	85.3	34°		
24	" " 15(16)	"	1.6	2.1	83.4	62°		(not good) 50° - 73°
25	" " 14(16)	"	1.5	0.9	83.5	76°	(not good)	62°
26	" " 13(14)	"	1.2	4.9	84.9	31°		(not good) 38°

* Height finder used.

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APPENDIX

A. Construction Data for Nomogram at Original Scale (fig. 9)

Distance from line of difference in parallax (dp) to:

a. line of turning points	130.07 mm
b. line of angle of dip	146.54 mm
c. line of horizontal distance	250.00 mm
d. line of adjusted photo base plus dp	280.00 mm
Length of lines	250.00 mm

Distance of logarithmic unit on line of:

a. difference in parallax (dp)	169.25 mm
b. turning points	81.19 mm
c. tangent of the angle of dip	72.28 mm
d. horizontal distance	156.05 mm
e. adjusted photo base plus dp	657.53 mm

To modify the nomogram at the original scale for use with any focal length, the scale of the angle of dip should be traced then overlaid on the fixed scale line, and shifted along the direction of this line on the nomogram a distance as determined below. The distance that the point on the dip scale marking 45 degrees will be above a line joining the 0.2 millimeter mark on the scale of the difference in parallax to the 120 millimeter mark on the scale of the adjusted photo base plus dp can be found from the following equation:

$$\text{distance} = 216.74 - (72.28) \log [(.04167)\ (\text{focal length in mm})]$$

To adjust for the reduced nomogram (fig. 9), the distance just obtained should be multiplied by the following fraction:

$$\frac{\text{length of scale lines on nomogram (fig. 9) in millimeters}}{250 \text{ millimeters}}$$

The above equation distance should be used in cases where the focal length is smaller than 240 millimeters. In cases where the focal length is 240 millimeters or more, the equation should be:

$$\text{distance} = 144.56 - (72.28) \log [(.004167)\ (\text{focal length in mm})]$$

The nomogram of figure 9 was constructed using the procedures described by A. S. Levins.[6]

To use the nomogram, lay a straight-edge on the nomogram so that it cuts a reading on both the scale lines of the difference in parallax and the adjusted horizontal distance. Mark lightly the point where the straight-edge crosses the line of turning points. Place the straight-edge so that it cuts this point and a reading on the scale line of the adjusted photo base plus difference in parallax. The dip in degrees can now be read on the dip scale line where the straight-edge crosses it.

[6] Levins, A. S., Nomography, New York, John Wiley and Sons, Inc., 1948.

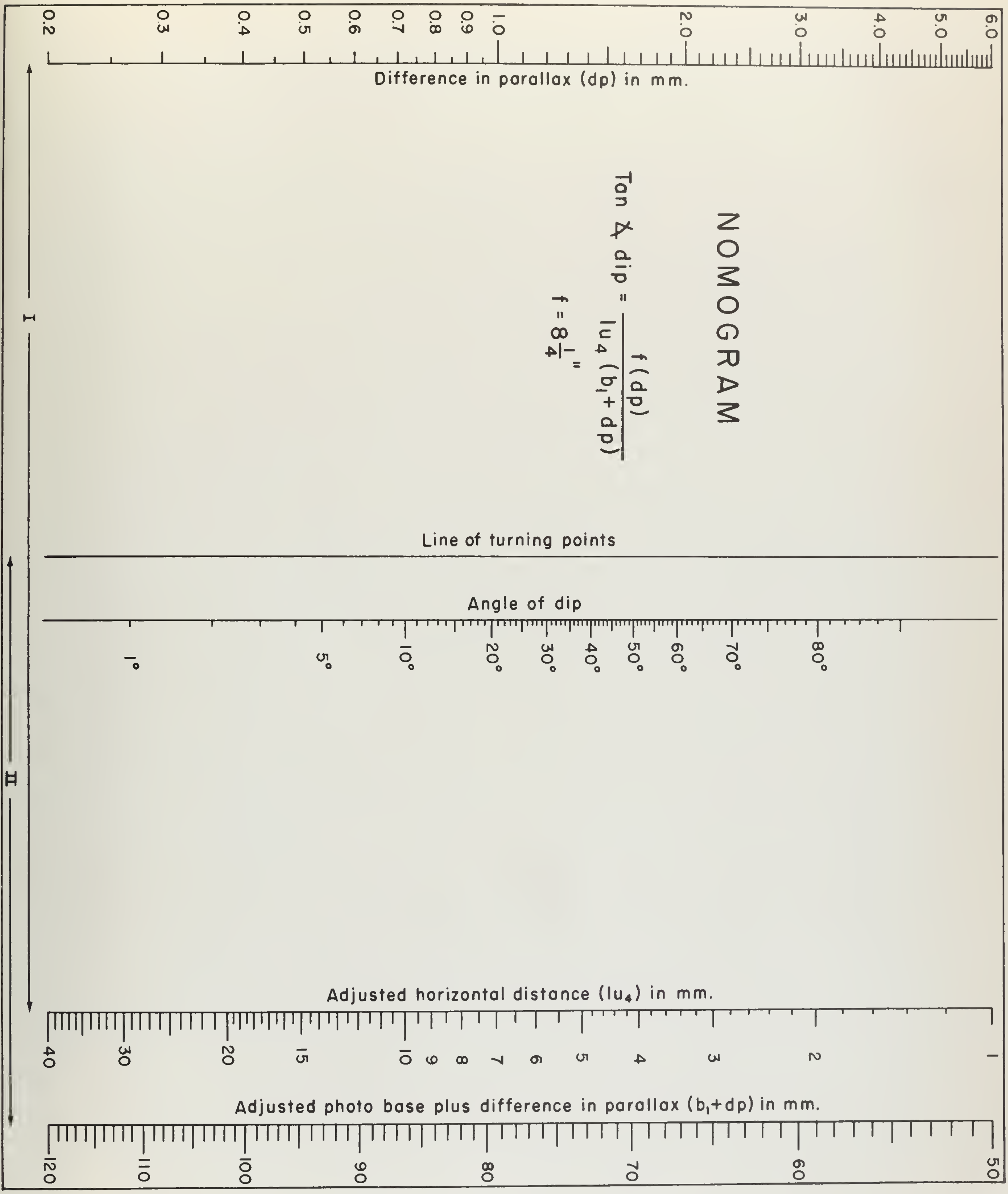

Figure 9. Nomogram for $8\frac{1}{4}$ inch focal length.

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